Design Review

Bicycle Tire Pressure Sensors

Team # 33

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Introduction:

Riding a bicycle with under-inflated or leaky tires can reduce traction and cause faster tire deterioration, but tire pressure monitoring systems are currently unavailable for bicyclists. A system that monitors the pressure as well as rate of change of pressure for the rider can be greatly beneficial to the riding experience via an easily interpreted display that warns of potentially dangerous pressure conditions.

Objectives:

Our goal is to design an easily integrable bicycle tire pressure sensor that will monitor both pressure and rate of change of pressure for the rider. The sensors will check measured pressure values against 65 psi, 55psi and 45psi thresholds, as well as compare the pressure to the previously measured values. The measured pressure value and any relevant warning flags will be wirelessly transmitted to the control unit mounted on the handle bars, which will control an LCD display. The LCD display will show the rider the current pressure values for both tires, and the corresponding pressure value will flash at varying speeds if pressure is too low and will flash "check tire" if there is a sudden change in pressure.

There may be cyclical irregularities in the sensor output caused by different levels of deformation in the tube as the tire rotates. If this is the case, then the circuit will instead sample faster and use the cyclical nature of the anomalies to determine the speed of rotation, and therefore the speed of travel.

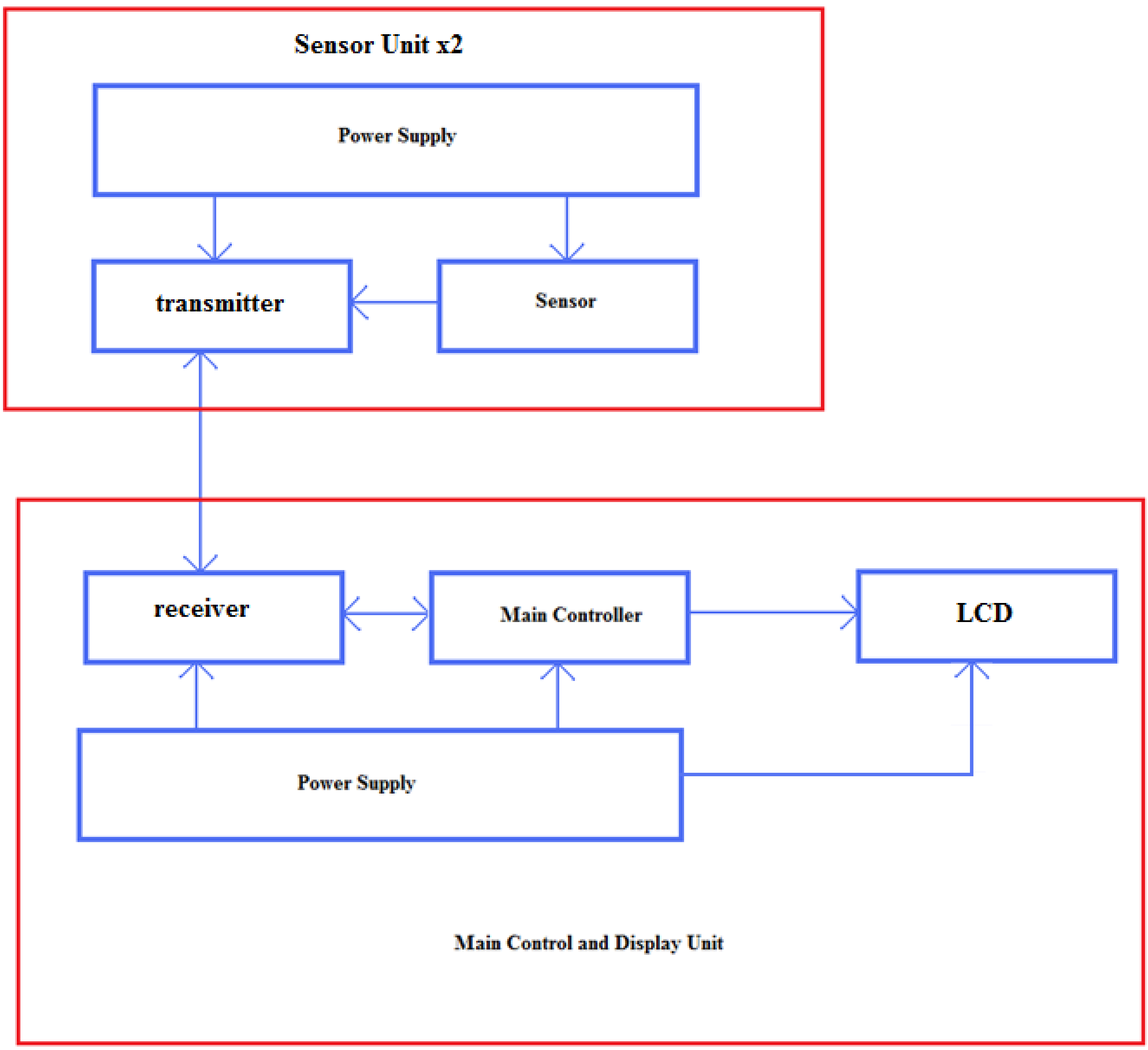
Benefits:

- Improve bicycle safety by warning riders of non-ideal tire conditions
- Prevent tire and wheel deterioration due to underinflated tires
- Alert riders to tire damage when rapid pressure changes occur

Features

- Simple, user friendly LCD display
- Constant tire pressure updates while riding
- Multiple samples to prevent false positives when the measured pressure becomes too low or the measured pressure changes too rapidly

Schematics:


Sensor Unit x2
Power Supply
transmitter
Sensor
receiver
Main Controller
LCD
Power Supply
Main Control and Display Unit

Block Descriptions:

The sensors will be implemented as a force sensor mounted between the rim and the tire tube. The sensor has variable resistance – less resistive the greater the force that is applied to it – which we will convert into a variable voltage via a non-inverting voltage amplifier op amp circuit. The voltage measurements will be made and A/D converted by a PIC, which will also store voltage measurements to estimate rate of change of pressure. The PICs will output the measurements and any necessary warning flags to the transmitters.

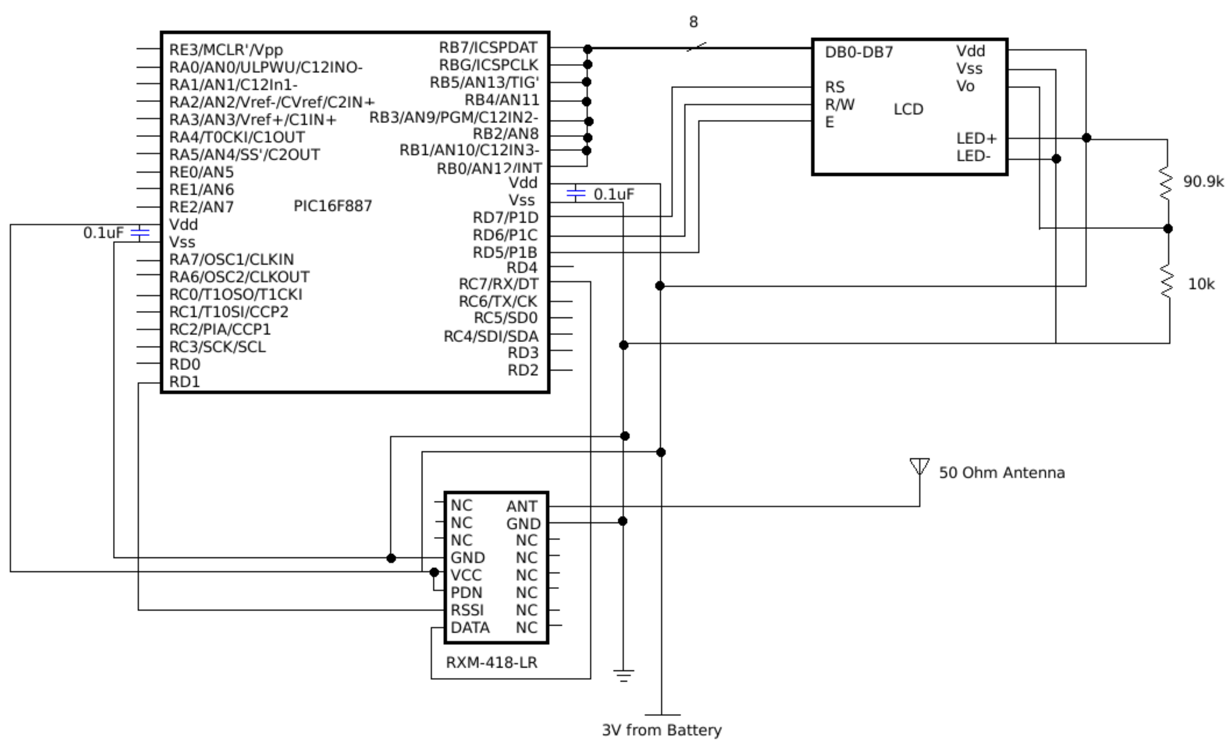
The transmitters will be implemented by Linx LR transmitter chips and antennae. The receiver unit will likewise be a Linx antenna and LR receiver chip.

The sensor power supplies power supplies will be implemented as two coin type batteries, and the handlebar unit will have 2 AA batteries. All three power supplies will supply 3V to their respective circuits.

The main controller will convert the received measurement data into control bits for the LCD.

While on, the LCD will display the most recent pressure measurement for each tire, flash if a tire has fallen below 65 psi and flash the words “check tire” if a tire’s pressure has fallen too rapidly.

The handlebar unit:



Handlebar Unit:

1. The handlebar mounted unit receives the pressure measurements and controls the LCD display.
2. Because the clocks of all three separate units are not synchronized, the central unit cannot predict when messages will be transmitted, and therefore putting the receiver in power down mode is not an option. However, easy accessibility allows for a switch that will turn off the handlebar unit when the bicycle is not in use to conserve power.
3. The unit mounted on the handlebars will also operate at 32kHz. Assuming the user is a very active cyclist who cycles 5 hours every day and always remembers to turn the unit off when he is done, this means the handlebar unit is on ${}^{5}/_{24} = 20.8\%$ of the time. Therefore, the microcontroller consumes:

$$P = 0.208 * (3V * 11\mu\text{A}) = 6.864\mu\text{W}$$

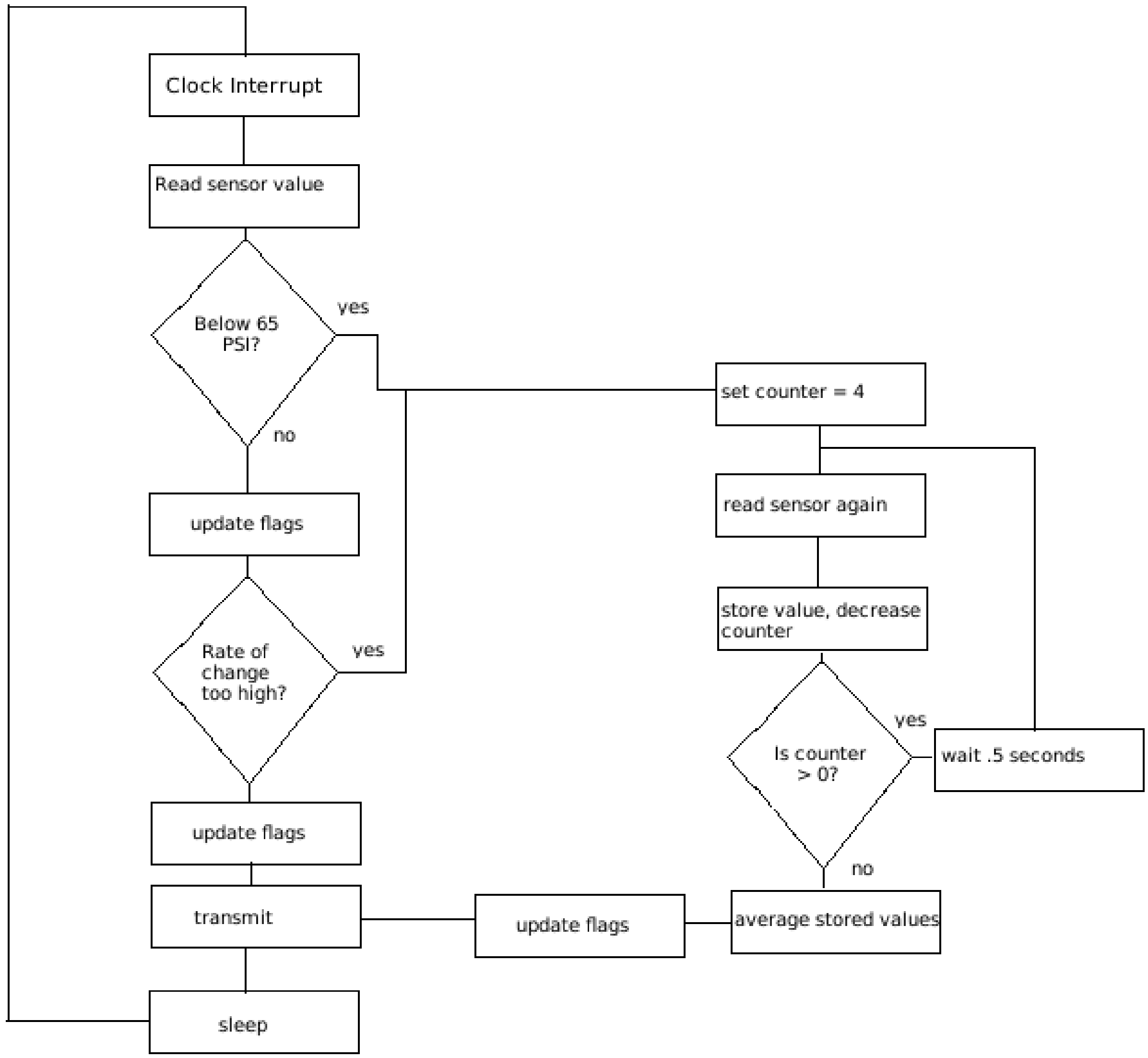
4. The receiver draws 5.2mA when active. Therefore, using the same assumptions as point 3, the power consumed by the receiver is:

$$P = 0.208 * (3V * 5.2m\text{A}) = 3.245m\text{W}$$

5. The total power consumed by the handle bar unit is then:

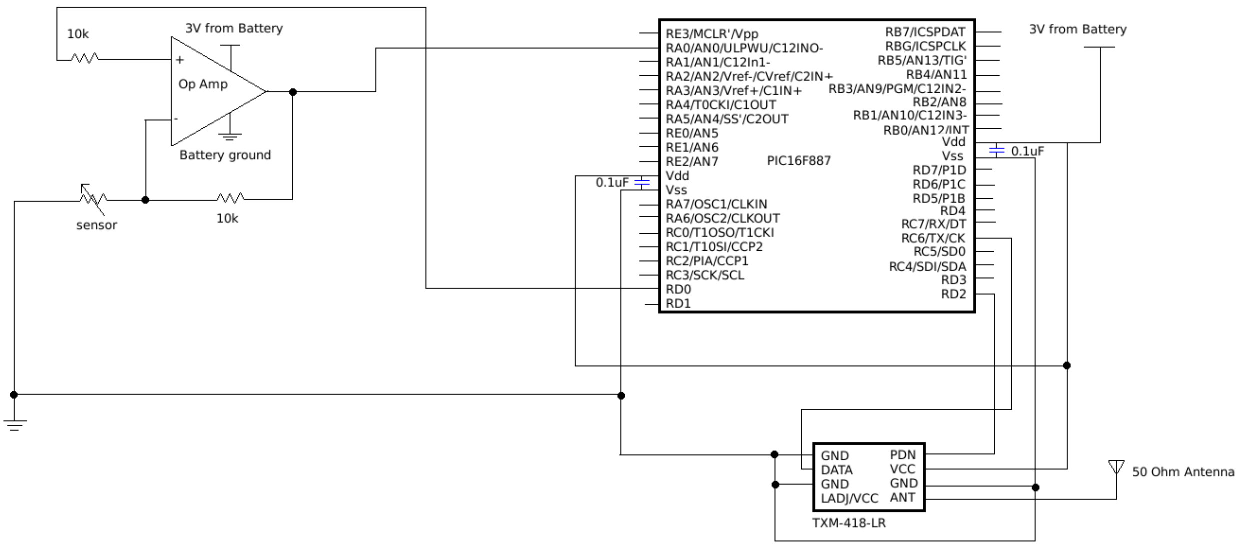
$$P = 3.245mW + 6.864\mu\text{W} \cong 3.245m\text{W}$$

6. This is much larger than the power consumed by the sensor units, therefore, to reduce the frequency of battery replacement, the handlebar unit will use larger batteries.
7. The software for the handlebar unit is illustrated by the following flowchart:



Clock Interrupt
Read sensor value
Below 65 PSI?
yes
no
update flags
Rate of change too high?
yes
update flags
transmit
sleep
set counter = 4
read sensor again
store value, decrease counter
Is counter > 0?
yes
wait .5 seconds
no
average stored values
update flags

The sensor unit (x2):



<u>Sensor unit:</u>

1. The sensor unit measures the pressure in the tube indirectly by measuring the force the tube exerts on a force sensor on the inside of the wheel.
2. The sensor is implemented as a flexiforce load sensor, chosen because of its incredibly small form factor and its slightly cheaper price compared to traditional load sensors.
3. The non-inverting op-amp amplifier serves to convert the variable resistance of the sensor into a voltage output that corresponds to pressure in the tube – higher pressures mean more force on the sensor, which reduces the resistance of the sensor, which in turn increases the output voltage of the amplifier.
4. The sensor's microcrontroller will run at 32kHz to conserve power, and in between measurements and transmissions the system will sleep to conserve even more power. When running at 32kHz current drawn is 11µA, and when sleeping the current drawn will be 1µA. Assume every 10 seconds a measurement will be taken and transmitted, and that measurement/transmission takes 5ms for regular measurements (95% of all measurements) and 20ms for measurements that are too low and require multiple samples (5% of all measurements). The power consumed by the microcontroller is then the power consumed by the PIC is:

$$P = \frac{(0.95*5ms+0.05*20ms)*(3V*11\mu\text{A})+\left(10s-(0.95*5ms+0.05*20ms)\right)*(3V*1\mu\text{A})}{10s} = 3.017\mu\text{W}$$

5. The transmitter will likewise power down in between transmissions to conserve power. When transmitting the transmitter will draw roughly 3.4mA and when

sleeping will draw 5nA of current. Using the same assumptions as for the microcontroller, power consumed by the transmitter can be calculated as:

$$P = \frac{(0.95*5ms+0.05*20ms)*(3V*3.4mA)+\left(10s-(0.95*5ms+0.05*20ms)\right)*(3V*5nA)}{10s} = 5.88\mu W$$

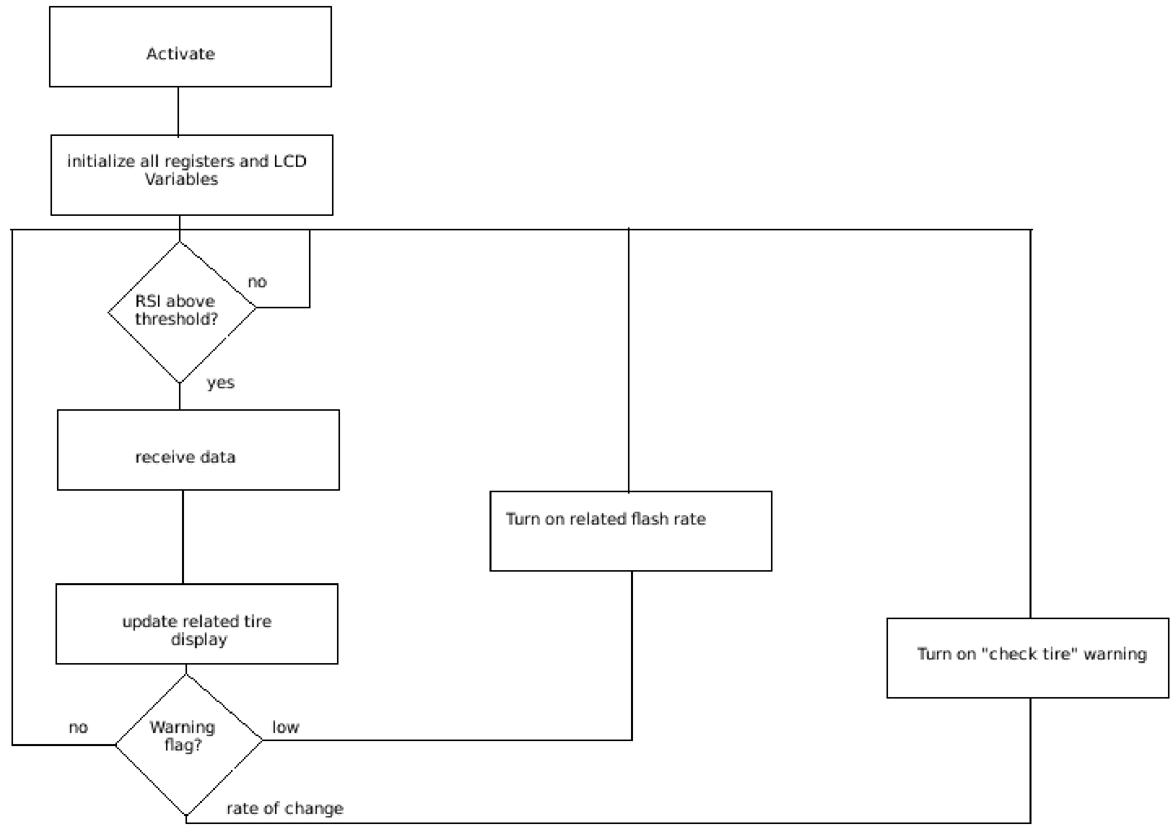
6. Finally, the sensor's resistance ranges from 5MΩ with no load to 20kΩ with the maximum rated load. Assuming the resistance averages at 40kΩ and that regular measurements require 3ms and repeated measurements require 15ms, then the power dissipated across the sensor is:

$$P = \frac{(0.95*3ms+0.05*15ms)*((3V)^2/40k\Omega)}{10s} = 0.129\mu W$$

7. Total power consumed is then:

$$P_{total} = 0.129\mu W + 5.88\mu W + 3.017\mu W = 9.026\mu W$$

8. It is our hope that the sensor circuits assembled on their PCB's will have a small enough form factor to allow them to be attached inside the wheel next to the sensor without causing significant deformation in the tube.
9. The required software for the sensor microcontrollers is illustrated by the following flow chart:



Verification:

Testing Procedures:

Pressure Sensor Testing – Since the entire project is based on gauging the amount of pressure within the tire, this is arguably the most important component to test. We will run multiple tests with varying amounts of air pressure being pushed down upon it. It is also necessary to make sure that it is durable enough for constant everyday use, so possible test rides followed by more testing may be necessary in order to ensure that it will function under slight stress. We want there to be as little error from what the sensor reads and what the actual pressure is, so optimum placement and reading of the sensor will be key.

Power Consumption Testing – Measuring the voltages and currents being drawn is also very necessary in order to ensure that our design will be able to last for a significant amount of time. We will calculate both the “On” and “Park Mode” current drawn from all components of the bike as well as determine what our power efficiency is.

Pressure Rate of Change Testing – Since this is the part of the project that make ours unique, it is important we are able to test this properly. We will be using the on-board memory of the MCU in order to compare present and past data from the sensor in order to gauge what the rate of change of the pressure inside of the tire is. Although the actual value will not be displayed, there will be a warning displayed if the rate of change of the pressure in the tire becomes too large.

Notes:

1. All voltage measurements are to be within 0.1% of the specified values.
2. For all comparisons between two signals using an oscilloscope we will check that they are visually indistinguishable.
3. For all digital signals, a bit error rate of less than 1 in 1000 is required.

Requirement	Verification
<u>Power Supply:</u> 1. All three power supply units will provide 3V and 100 μA to their respective circuits. 2. The handle bar unit’s power supply will provide 3V when active and 0V when in “park mode.”	1. DC voltage measurements made with a multimeter across the ports on the battery holders will confirm that the batteries are supplying 3V. We will then connect a 30 kΩ resistor and multimeter to each battery holder to ensure that 100 μA is drawn. 2. DC voltage measurements made with a multimeter across the supply voltage pins of each the receiver, PIC, and LCD in the handlebar unit to ensure that voltage is being supplied when the switch is in the on position and is no longer being supplied otherwise.

<u>Sensors:</u> 1. The sensors will output a series of bits corresponding to within 10% of the correct pressure value. a. Both flexiforce sensors should have resistance values that correspond to within 10% of the correct applied force value as determined by testing. b. The non-inverting amplifier will output the correctly amplified voltage value. c. The Microcontroller serial outputs will properly output the A/D converted sensor voltage and the necessary warning flags.	1. We will apply 5, 10 and 20 pounds of force onto the sensor and monitor the output of the microcontroller to the transmitter with an oscilloscope. a. We will apply 5, 10 and 20 pounds to the sensors and use a multimeter to measure the resistance across the two leads, and then compare the measured values to the expected values as determined by the relationship we discover through testing the sensors. b. With 10 pounds of force on the sensor we will apply a 1.5V test voltage to the input of the amplifier and read the output with a multimeter and compare this voltage to the expected voltage for Rs given 10 pounds of force. c. We will supply 1V, 1.5V and 2V to the A/D input pin of the PIC using a function generator and read the output from the TX port with an oscilloscope and compare these bits to the expected output (the exact transmission scheme has yet to be determined).
<u>Transmitters:</u> 1. The transmitter module must emit a signal that is without errors and strong enough to be received by the handlebar unit. a. The transmitted signal must be readable at a distance of 4 feet away from the antenna. b. The transmitter must output the correct signal to the antenna that corresponds to the input data.	1. We will use a function generator to input a 3V peak to peak, 10 kHz square wave to the transmitter data input, then observe the received signal from the receiver antenna set 4 feet away from the transmitter with an oscilloscope. a. We will use a function generator to input a 3V peak to peak, 10 kHz square wave to be modulated onto a 418 MHz sine wave directly to the antenna, and then use an oscilloscope to read the received wave from the receiver antenna at a distance of 4 feet away. b. We will again use a function generator to input a 3V peak to peak, 10 kHz square wave to the transmitter, and this time we will use an oscilloscope to observe the signal output from the transmitter to the antenna and compare this to the expected sequence.

<table>
<tr><td><u>Receiver</u>

1. The receiver module must output the correct data bits when a transmitted signal is present.

a. Given that the signal with adequate power, the receiver antenna should output the signal to the receiver module
b. The receiver module will output the correct series of bits to the PIC.</td><td>1. Using a function generator, we will directly input a 3V peak to peak, 10 kHz square wave modulated onto a 418 MHz sine wave to a transmitter antenna, then monitor the data output of the receiver module with an oscilloscope.

a. Transmitter test 1.a also confirms this.
b. Again, the function generator will generate a 3V peak to peak, 10 kHz square wave modulated on a 418MHz sine wave, which will act as a direct input to the receiver module. We will then observe the output of the receiver module with an oscilloscope</td></tr>
<tr><td><u>Main Controller:</u>

1. The proper control signals for the LCD will be generated by the PIC for a given serial input to the RX pin.</td><td>1. Using a function generator, we will supply the series of bits corresponding to 80 psi and no warning flags for both tires to the RX pin and a sufficiently high voltage as a fake RSSI value, then we will monitor the output control signals with an oscilloscope and compare to the expected values.
2. We will then repeat this for 65 psi and a rate of change warning, as well as 55 psi.</td></tr>
<tr><td><u>LCD:</u>

1. The LCD must display the correct information corresponding to its control inputs.</td><td>1. Using a test program, the PIC will send the control bits to display “Hello” on the top line of the LCD and “World” on the bottom line, and we will observe the LCD.</td></tr>
</table>

Tolerance Analysis:

Since the pressure sensor is the most crucial part of our design, we want to make sure that it is reading the values given from the tire frequently and accurately. Our goal is to have it read the correct tire pressure to within 10% margin of error. Also, since battery replacement will be mildly inconvenient for the user, we will need to make sure that power efficiency is very high. Through the use of “Park Mode”, which is the mode that the bike will be in for approximately 90% of the time, we should be able to use very low amounts of power which will lead to increased battery life.

Ethical Concerns:

We will need to ensure that the transmitted field strength from our sensor units falls below the legal limits as set by the FCC.

Parts:

Part #	Manufacturer	Description	Price	Qty	Total
TXM-418-LR	Linx	Wireless Transmitter	$6.39	2	$12.78
RXM-418-LR	Linx	Wireless Receiver	$13.56	1	$13.56
PIC16F887	Microchip	Microprocessor	$2.84	3	$8.52
30056-ND	Parallax	Force Sensor	$27.65	2	$55.30
796136-1	TE Connectivity	Coin Battery Holder	$1.592	4	$6.368
SY189-ND	FDK America	Coin Battery	$0.41	4	$1.64
N103-ND	Energizer	AA Battery	$0.33250	2	$0.665
BC2AAW-ND	MPD	AA Battery Holder	$0.85	1	$0.85
LMK105BJ104KV-F	Taiyo Yuden	0.1µF Capacitor	$0.04	6	$0.24
NHD-0220FZ-FSW-GBW-P-3V3	Newhaven Display	LCD	$12.15	1	$12.15
ERJ-3GEYJ910V	Panasonic - ECG	90.9 kΩ Resistor	$0.02	1	$0.02
ERJ-3GEYJ103V	Panasonic - ECG	10 kΩ Resistor	$0.02	3	$0.06
OPA131UJ	Fairchild Semiconductor	Op Amp	$2.81	2	$5.62
ANT-418-HESM	Linx	Antenna	$1.04	3	$3.12
Total					$120.893

Labor = 160hours*40$/hour*2 = 12800

Total Cost = Labor + Parts = 12800+114.803 = $12920.893

Schedule:

Week	Michael	Bryan
2/5	Research Parts	Write Proposal
2/12	Order Parts	Finalize Design
2/19	Adjust design according to design review	Take measurements in lab
2/26	Code microcontrollers	Find optimum implementation for attaching to bike
3/4	Interface microcontrollers with transmitters and sensors	Interface microcontroller with LCD display and receiver
3/11	Finish building sensor circuit	Finish building main controller circuit
3/18	Spring Break	Spring Break
3/25	Build casing and attachment for sensor circuit	Build casing and attachment for controller circuit
4/1	Test sensors while on wheels	Test main control unit on bike
4/8	Debug/final adjustments for sensors	Debug/final adjustments for main control unit
4/15	Final test runs	Analyze data from final test runs
4/22	Write final report	Write final report
4/29	Demo	Demo